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Sediment Physical Properties and Sound Velocity Measurements from Sediment Cores Taken Off the Washington and Oregon Coasts

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ABSTRACT:

Sediment cores were collected in the shallow and deep water areas off the Washington and Oregon coasts. Cores taken in deep water penetrated usually one, but sometimes two, stratigraphic units: a lower unit consisting of dark gray silty mud and an upper unit consisting of homogeneous olive gray mud. Differences between the two units are reflected in the physical properties measurements presented in this technical note. In general, the olive gray sediment is a homogeneous silty clay that is watery and poorly consolidated. The dark gray sediment, in contrast, is typically a clayey silt that is much firmer and less watery. The shelf sediment was found to contain greater amounts of coarse material and to be still firmer and less watery than the dark gray sediment.

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INTRODUCTION:

Sediment cores were collected (August, 1987) primarily to support of ocean bottom seismometer experiments conducted in shallow and deep water areas off the Washington and Oregon coasts. The experiments were designed to collect geoacoustic information and to use this information to validate existing geoacoustic models. Specifically, the cores provide detailed information concerning the physical and acoustical properties of the surficial sediments.

GENERAL GEOLOGY:

The bulk of the Holocene deposits that characterize the continental slope and Astoria submarine fan off the Oregon coast are chiefly olive gray, dark olive gray, and dark gray muds. These deposits consist of terrigenous clayey silt and silty clay and are, therefore, hemipelagic in nature. On the Astoria Fan the muds are interbedded with turbidite layers consisting of coarse silt and fine sand. Cores taken on the fan typically show a surface veneer of Holocene mud ranging in thickness from a few centimeters to a few meters.

Two stratigraphic units are usually penetrated by piston cores taken on the fan. The lower unit is a dark gray silty mud of indeterminant thickness that is interbedded with numerous sand layers and silt laminae. The overlying olive gray mud unit typically has a homogeneous clay lithology, is watery and poorly consolidated. Cores taken on the fan usually penetrate only the upper part of the dark gray silty mud unit which appears to have been deposited during the Late Pleistocene (Late Wisconsin).

CORE LOCATIONS:

Sediment cores were taken at the locations listed in Table 1 and shown in Figures 1 and 2. Core 1 was taken near the base of the continental slope and core 2 was taken on the lower middle part of the slope. Cores 3 through 5 were taken on what is thought to be a mud volcano that rises a few hundred meters above the level of the Astoria Fan (no mud was recovered by core 3). Core 6 was taken on

the fan. Cores 7 and 8 were taken on the continental shelf just before it plunges steeply to form the south wall of Nitinat Canyon.

SEDIMENT RECOVERY:

All the cores, with the exception of cores 7 and 8, recovered olive gray mud which is characteristic of this area. In addition, cores 1 and 5 penetrated an underlying dark gray mud which probably correlates (in time) with the lower stratigraphic unit of the Astoria Fan. Although core site 5 is located on the fan (Fig. 1), the core itself is actually from the mud volcanoe as noted above. Therefore, it does not contain the coarse turbidite layers that characterize the lower unit of the fan.

Only a few rounded rock fragments were recovered in core 7. This, and the fact that the core cutter was slightly damaged, indicates that the corer encountered a gravely bottom which it could not penetrate. Core 8, taken near by, penetrated 128 cm into the bottom. The top 7 cm of sediment consisted of coarse sand with the remaining 121 cm consisting of very firm mud. Cores 7 and 8 indicate that the lithologies of the shelf sediments may vary substantially over short lateral distances.

MEASUREMENTS:

Physical properties and sound velocity (compressional) measurements (Table 2) were made in the laboratory. Grain size was determined using a Micromeritics sediment analyzer (fine fraction) and standard seiving techniques (coarse fraction); grain density, void ratio, porosity, and wet bulk density were calculated using weight/volume techniques; water content values are based on weight loss (wet vs dry weight); shear strength measurements were made using a vane shear apparatus; and velocity measurements (uncorrected) were made using an Underwater Systems velocimeter. See Lambe (1951) for details concerning the above physical properties measurement techniques.

OLIVE GRAY SEDIMENT MEASURMENTS:

Grain Size:

Grain size analyses show the samples from the olive gray sediment to be silty clays. Texturally, the sediment is fairly uniform with silt fractions usually ranging between about 30-46%, and 61-69% for the clay. The sand fraction (0.6-3.7%) is low. The mean grain size range is 8.2-8.8 phi with an average of 8.6 phi.

Water Content, Porosity, Void Ratio:

With one exception (sample 59-61 cm, core 1) the water content of the olive gray unit is usually well over 100% (percent dry weight) indicating a very watery sediment. Approximately one-half of the twenty-one samples have water contents of 127-140%. The highest water content is 180% and the average water content is about 133%. With few exceptions, the porosities fall between 72-80% with an average value of 77%. Void ratios range from a low of 2.33 (associated with the lowest water content and porosity) to a high of 4.52 (highest water content and porosity). The average void ratio for the olive gray unit is 3.41.

Grain Density:

Although the grain densities varied from 2.50-2.66 gm^3, most of the samples were more narrowly grouped from 2.54-2.62 gm^3. The average value for all samples is 2.58 gm^3. These densities are somewhat lower than might be expected for a predominantly fine-grained, hemipelagic sediment. The presence of organics could account for the lower values.

Wet Bulk Density

Most values for wet bulk density fall within the range of 1.30-1.37 gm^3. The average for all samples of the olive gray sediment is 1.36 gm^3. These densities are lower than the density quoted by Hamilton (1980) for an average silty clay (1.42) and reflect the high porosity and moisture content of the olive gray sediment.

Shear Strength:

Shear strengths for the olive gray unit range between 2.2 kPa and 5.9 kPa with and average value of 4.2 kPa. Typically, the shear strengths showed a tendency to increase with depth in the sediment.

Sound Velocity:

Sound velocity measurements range between 1480-1496 m/sec with an average of 1488 m/sec. These velocities are substantially lower than the velocity given by Hamilton (1980) for an average silty clay (1520 m/sec) and once again may reflect the generally high water content and porosity or the olive gray sedimentary unit.

DARK GRAY SEDIMENT MEASUREMENTS:

Grain Size:

Only two samples were analyzed from the lower dark gray unit. In core 1 the sample (103 cm) is only slightly more silty (mean

grain size = 8.3 phi) than the olive gray sediment whereas the sample from core 5 (59-61 cm) is a clayey silt with a mean grain size of 8.0 phi.

Water Content, Porosity, Void Ratio:

Porosities for six samples analyzed from the dark gray sediment fall between 64-72% with an average of 67.6%; still within the range of a silty clay. The lower porosities are reflected by lower water contents (64-94%) which are usually well below 100% (ave. = 79%) and generally lower void ratios (1.82-2.53; ave. = 2.11).

Grain Density:

The higher grain densities for the dark gray sediment (2.67-2.69 gm^3) probably reflect a slighly higher terrigenous component (silt) than found in the olive layer.

Wet Bulk Density:

Wet bulk densities range from 1.48-1.60 with an average of 1.54 and are consistent with the lower porosity, moisture content, and void ratio of dark gray sediment. These values are comparable with the value given by Hamilton (1980) for silty clay.

Shear Strength:

The firmer nature of the dark gray unit is reflected by a higher range of shear strengths (5.3-17.8 kPa). The average shear strength for this layer is 9.4 kPa, but this is based on only five measurements

Sound Velocity:

The dark gray sediment showed a much wider spread of values, ranging between 1477-1515 m/sec with an average value of 1498 m/sec. Considering the nature of the sediment, the values of 1477 m/sec and 1485 m/sec in core 5 are particularly suspect. Velocities above 1500 m/sec are probably more realistic for this sediment.

SHELF SEDIMENT MEASUREMENTS:

Grain size:

The core recovery for cores 7 and 8 indicate that the shelf sediments may consist of coarse gravel, sand, or mud depending upon location. Analysis of core 8 indicates that the finer sediment is a clayey silt to sandy silt. Among the three samples analyzed, the silt content varied the least with most of the variation being shared by the sand and clay contents. The mean grain size for the clayey silt sample is 6.7 phi and the mean for the sandy silt samples is about 6.5 phi.

Water Content, Porosity, Void Ratio:

The firm consistency and low clay content of core 8 shows in the low values measured for these three parameters. Water contents ranged from just under 34-61%, porosities from 48-62%, and void ratios from 0.92-1.66. Average values for these measurements were 46.9%, 55.3%, and 1.27%, respectively.

Grain Density:

The densities, with the exception of one (2.68 gm^3), are narrowly grouped from 2.70-2.72 gm^3. These densities are typical for predominantly fine-grained (clay) sediment. In the case of core 8 which is predominantly coarse-grained, the densities probably reflect the predominance of basaltic sand and silt which have a higher grain density than quartz sand and silt (2.65 gm^3).

Wet Bulk Density:

Densities of 1.64-1.90 gm^3 characterized core 8. The average density is 1.76 gm^3. The average value is very close to the average value (1.77 gm^3) given by Hamilton (1980) for a typical sandy silt.

Shear Strength:

As expected from the firm nature of this sediment, the shear strength is high for the entire core. Values ranged from a low of 10.5 kPa to a high of 19.6 kPa with an average value of 13.5 kPa. Surprisingly, the sediment strength decreases downcore before reaching a maximum strength at the bottom. The lower shear strengths for the middle portions of the core may result from the generally higher moisture contents and porosities found here than found at either the top or bottom.

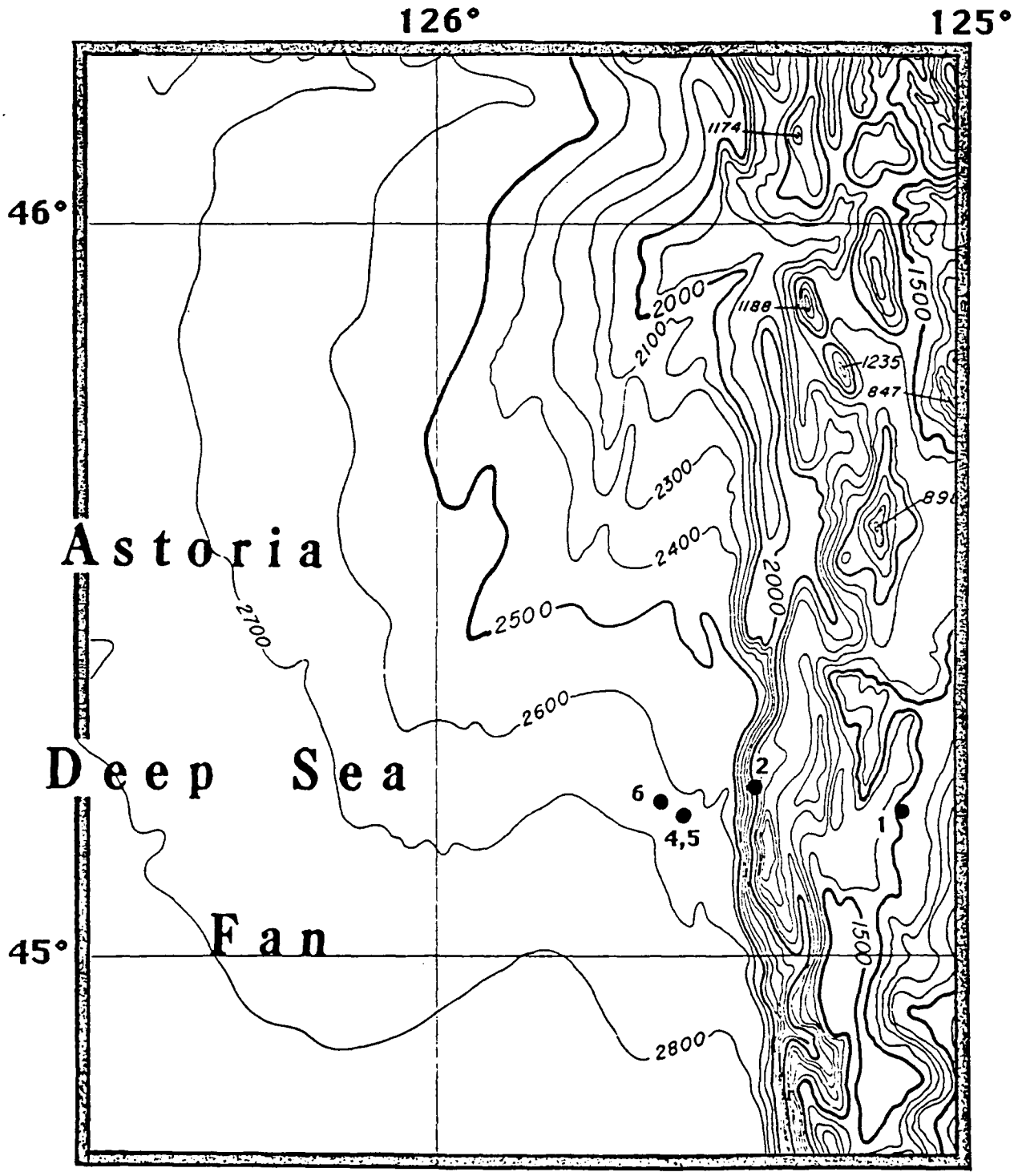
Sound Velocity:

The relationship between sound velocity and grain size is well established; the coarser the sediment the higher the sediment velocity. This is clearly seen in core 8 which has the highest velocities of all the cores taken. The velocities range from 1508 m/sec to 1563 m/sec with an average of 1531 m/sec. Similar to the shear strength values, the sound velocity values also decrease downcore before increasing near the bottom.

REFERENCES:

Hamilton, E.L. (1980). Geoacoustic modeling of the sea floor. J. Acoust. Soc. Am. 68(5): 1313-1340.

Lambe, T.W. (1951). Soil Testing for Engineers. John Wiley & Sons, Inc., New York. 165 pp.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125°
46°
45°
Astoria
Deep Sea
Fan
1174
2000
1188
2100
1500
1235
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2300
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2600
2000
1500
2800
6
4,5
2
1

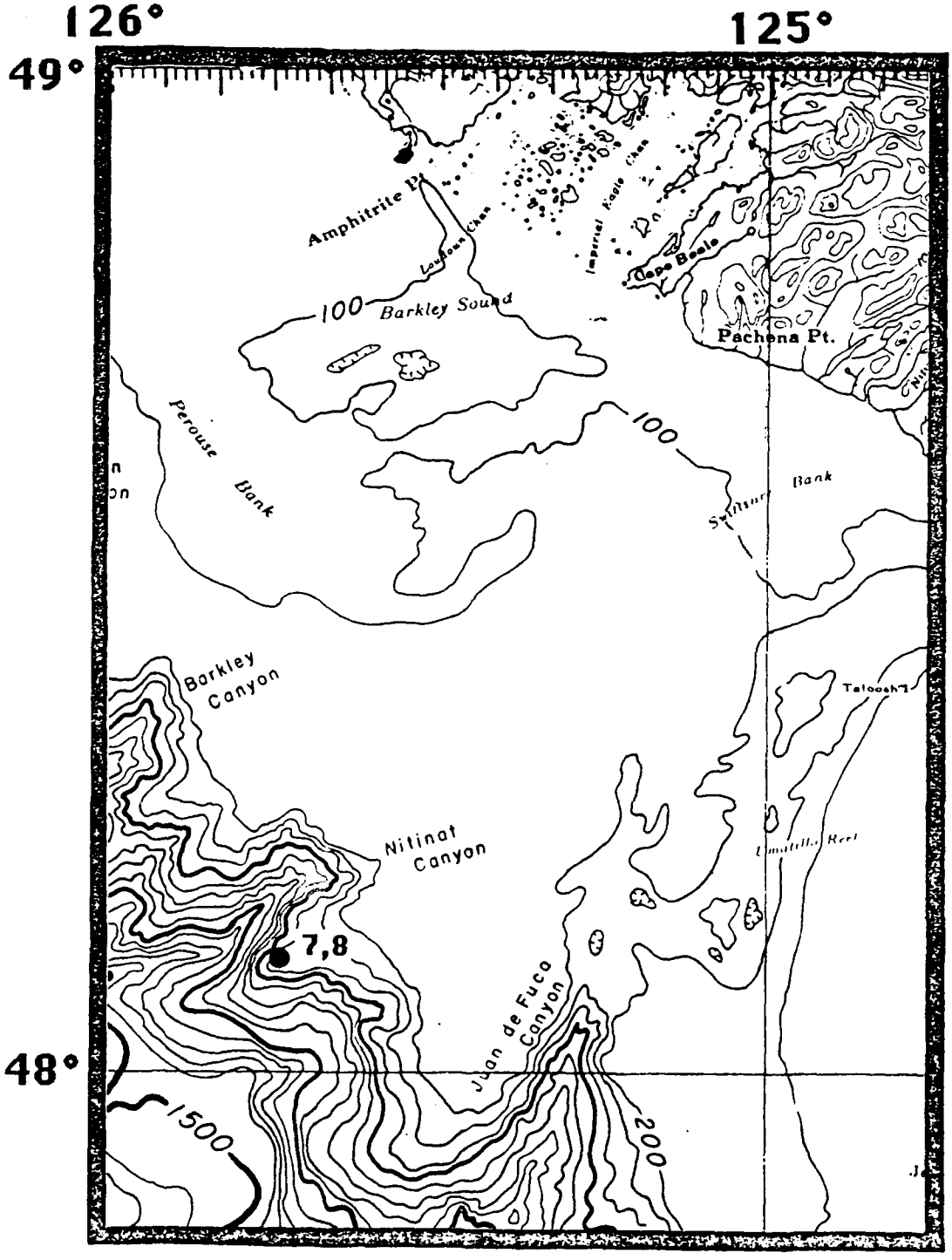
126°
125°
49°
48°
Amphitrite Pt.
Cape Beale
Pachena Pt.
100
Barkley Sound
Perouse Bank
Barkley Canyon
Nitinat Canyon
7,8
Juan de Fuca Canyon
1500
200

TABLE 1

Core	Latitude(°n)	Longitude(°w)	Water Depth(fm)
1	45°13.74'	125°23.20'	1837
2	45°11.80'	125°06.20'	1575
4	45°11.67'	125°31.32'	2440
5	45°11.76'	125°31.67'	2438
6	45°12.52'	125°34.08'	2645
7	48°07.07'	125°44.19'	257
8	48°07.22'	125°44.61'	250

TABLE 2

CORE #	SAMPLE INTERVAL (CM)	COLOR (MUNSELL)	DESCRIPTION	MEAN GRAIN SIZE (Phi)	SAND %	SILT %	CLAY %	WATER CONTENT %	GRAIN DENSITY (gm/cc)	POROSITY %	VOID RATIO	WET BULLS DENSITY (gm/cc)	SHEAR STRENGTH (kPa)	SOUND VELOCITY (m/sec)
1	0	5y4/2	Olive gray	8.2	2.8	40.4	56.8							
	23-25	"	mud, soft					112.2	2.58	74.3	2.89	1.41	4.8	1494
	30--	"	sticky, homo-											1491
	38-40	"	genous, sharp					104.2	2.59	72.9	2.70	1.43	5.9	1491
	44-46	"	color, boundary					113.2	2.60	74.6	2.92	1.41		
	50-	"	at 75 cm											1491
	59 -61	"						88.8	2.62	69.9	2.33	1.49	9.0	1491
	70-	"						88.8	2.62	69.9	2.33	1.49	9.0	1491
	78-80	5y4/1	Dark gray mud,					70.1	2.68	65.3	1.88	1.58	17.8	1502
	90-	"	homogeneous, firm											1502
	95-97	"						67.9	2.68	64.5	1.82	1.60		
	103	"		8.3	4.6	36.5	58.9							

TABLE 2 (con't)

CORE #	SAMPLE INTERVAL (CM)	COLOR (MUNSELL)	DESCRIPTION	MEAN GRAIN SIZE (Phi)	SAND %	SILT %	CLAY %	WATER CONTENT %	GRAIN DENSITY (gm/cc)	POROSITY %	VOID RATIO	WET BULK DENSITY (gm/cc)	SHEAR STRENGTH (kPa)	SOUND VELOCITY (m/sec)
2	3.5 - 4.5	5y4/2	Olive gray mud homogeneous, soft sticky	8.7	1.0	34.6	64.4	134.1	2.54	77.3	3.41	1.35		
	10 -													1480
	15-17							159.9	2.52	80.1	4.03	1.30		
	22-24							180.9	2.50	81.9	4.52	1.27	3.2	1486
	30													1489
	41-43							154.0	2.51	79.4	3.86	1.31	3.4	1487
	50													1485
	62 - 64							151.4	2.54	79.4	3.84	1.32	4.5	1483
	70													1481
	83-85							132.3	2.54	77.1	3.36	1.35	5.6	1484
	90													1482
	103 - 105							131.2	2.56	77.1	3.36	1.36	5.8	1483
	110 -													1480
	122 - 125							127.0	2.58	76.6	3.28	1.37	5.8	1480
	130													1482
	138 - 140			8.7	0.6	35.6	63.8	130.5	2.56	77.0	3.34	1.36		
	146													

TABLE 2 (con't)

CORE #	SAMPLE INTERVAL (CM)	COLOR (MUNSELL)	DESCRIPTION	MEAN GRAIN SIZE (Phi)	SAND %	SILT %	CLAY %	WATER CONTENT %	GRAIN DENSITY (gm/cc)	POROSITY %	VOID RATIO	WET BULK DENSITY (gm/cc)	SHEAR STRENGTH (kPa)	SOUND VELOCITY (m/sec)
4	0 -	5y4/2	Olive gray mud,	8.7	1.7	31.4	66.9							1494
	10-	"	homogeneous, soft											
	19-21		sticky					135.7	2.61	78.0	3.54	1.35	2.4	1493
	30	"												1493
	41-43	"						136.4	2.62	78.1	3.57	1.35	5.1	1491
	52-54	"		8.5	3.7	31.5	64.8	128.0	2.61	77.0	3.34	1.37		1489
	57	"												1496
	60	"												
5	0 -	5y4/2	Olive gray mud,	8.4	2.0	36.6	61.4							1485
	12 -	"												
	23 - 25	"	homogeneous, soft					133.4	2.62	77.8	3.50	1.36	2.4	1485
	30 -	"	sticky											1486
	39 - 41	"						107.2	2.66	74.0	2.85	1.43	3.8	1492
	50 -	"												1485
	59 - 61	5y4/1	Dark gray mud,					94.0	2.68	71.6	2.52	1.48	5.3	1496
	70	"	homogeneous, soft											1493
	81 - 83	"	sticky, a few very					80.8	2.67	68.3	2.16	1.53	7.0	1485
	90	"	thin (mm) silt laminae											1477
	101 - 103	"						90.9	2.69	71.0	2.44	1.49	7.9	1515
	110 -	"												1515
	124 - 126	"		8.0	0.5	54.3	45.2	68.5	2.69	64.8	1.84	1.59		
	130													

TABLE 2 (con't)

CORE #	SAMPLE INTERVAL (CM)	COLOR (MUNSELL)	DESCRIPTION	MEAN GRAIN SIZE (Phi)	SAND %	SILT %	CLAY %	WATER CONTENT %	GRAIN DENSITY (gm/cc)	POROSITY %	VOID RATIO	WET BULK DENSITY (gm/cc)	SHEAR STRENGTH (kPa)	SOUND VELOCITY (m/sec)
6	3 -	5y4/2	Olive gray mud											1492
	9 - 12	"	homogeneous, soft	8.6	1.0	35.2	63.8	157.2	2.56	80.1	4.02	1.31		1490
	20 -	"	sticky										2.2	1490
	25 - 27	"						140.7	2.56	78.3	3.60	1.34		
	30 -	"												1489
	40 -	"											4.1	1486
	43 - 45	"		8.9	0.5	30.3	69.2	131.5	2.61	77.4	3.43	1.36		
	52	"												
8	0 - 7	5y3/2	Dark olive gray sand with rounded to sub-rounded rock fragments (0.5 - 3.0 cm in size)											
	10 - 12	2.5yN4	dark gray mud	6.4	15.1	56.2	28.7							
	21 - 23		gritty, very firm, a					33.7	2.72	47.8	0.92	1.90	14.8	
	30 -		few silty laminae,											
	37 - 39		occassional small					34.8	2.72	48.6	0.95	1.88		
	41 - 43		(a few mm's)rock					41.4	2.70	52.8	1.12	1.80	12.1	1563
	50		fragments.											1549
	57 - 59							58.0	2.71	61.1	1.57	1.66		
	61-63			7.6	5.9	48.3	45.7	61.1	2.72	62.4	1.66	1.64	12.3	1538
	70													1519
	77 - 79							37.8	2.70	50.5	1.02	1.84		
	81 - 83							46.8	2.70	55.8	1.26	1.75	10.5	1514
	90													1508
	97 - 99							60.8	2.68	62.0	1.63	1.64		
	102 - 104							50.2	2.72	57.7	1.36	1.73	11.6	1520
	110													1534
	120													
	124 - 126			6.5	19.9	49.8	30.1	34.7	2.70	54.7	1.21	1.77	19.6	

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